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(71) Applicant (*for all designated States except US*): IPEC PRECISION, INC. [US/US]; 3 Berkshire Boulevard, Bethel, CT 06801 (US).

(71)(72) Applicant and Inventor: SINIAGUINE, Oleg [RU/US]; 11 Red Barn Road, Oxford, CT 06478 (US).

(72) Inventor; and

(75) Inventor/Applicant (*for US only*): TOKMOULINE, Iskander [RU/US]; 23 Marjorie Drive, New Fairfield, CT 06812 (US).

(74) Agent: VAN WINKLE, Peter, H.; Ware, Fressola, Van Der Sluys & Adolphson, Bradford Green, Building Five, 755 Main Street, P.O. Box 224, Monroe, CT 06468-0224 (US).

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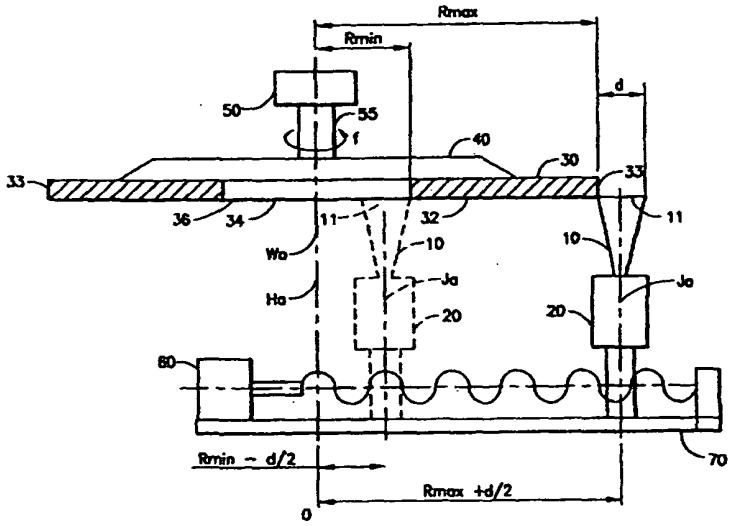

(57) Abstract

A method for treating an article with a plasma jet is disclosed. The method involves rotating an article (30) with a surface (32) to be treated about an axis (Ha), wherein the rotation defines a rotation radius extending from the axis. The article surface is contacted with the plasma jet (10) to form a plasma jet footprint (11) having a predetermiend dimension on the article surface. The plasma jet footprint is moved along the rotation radius in the radial direction according to a velocity profile along the rotation radius so as to apply heat to the article surface to obtain a desired temperature distribution profile on the article surface along the rotation radius. The method provides a means for controlling the temperature of the article uniformly in a temperature range from about 30 °C and 1200 °C to allow different treatment applications to be performed on the article.

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METHOD FOR TREATING ARTICLES WITH A PLASMA JET

BACKGROUND

Field of the Invention

The present invention relates to a method for treating the surface of articles, such as silicon wafers, with a plasma jet. More particularly, the present invention relates to a method for moving a plasma jet tool relative to the surface of an article being treated by the plasma jet tool.

Description of the Prior Art

A plasma jet is a confined and very intensive heat source. Typically, plasma jet tools have a cross section or footprint which is significantly less than the cross sectional area of a surface of an article, such as a silicon wafer, being treated by the plasma jet. Prior art plasma jet treatment of articles typically involves the production of a plasma jet which is directed at the article's surface. While the plasma jet is directed at the article's surface, the plasma jet is moved relative to the surface, usually by linear scanning, such as an X-Y linear scan.

Such prior art plasma jet treatment methods using linear scanning can result in damage caused by local overheating of the surface. In the case of silicon wafers, local overheating can result in crystal structure defects, wafer melting, high temperature gradient induced stresses, and breakage. Also, with prior art plasma jet wafer treatment methods, providing uniformity of plasma jet treatment to wafers of differing dimension can be problematic.

More specifically, several deficiencies in prior art linear scanning methods include low throughput and high potential for wafer damage. Every linear movement of the plasma jet across the wafer produces hot lanes at the wafer surface with cold surfaces adjacent thereto. The hot lanes tend to produce high temperature gradients, which in turn causes stress in the wafer. In order to avoid high temperature gradients, a delay must be made between adjacent hot lanes to allow for partial cooling of a previous hot lane and lowering of temperature

gradients to avoid wafer surface overheating or thermal stress induced wafer damage. As many linear scan movements have to be made to treat the entire wafer surface with sufficient delays to prevent thermal damage to the wafer, resulting wafer treatment throughput suffers.

The linear scan methods of the prior art also have the drawback that surface treatment quality suffers due to redeposition on the wafer surface caused by the contact of etch products with cold wafer surface near a hot lane.

SUMMARY OF THE INVENTION

The present invention relates to a method for treating a surface of an article with a plasma jet. According to the method, an article having a surface to be treated and a plasma jet is provided. The article is rotated about an axis so as to define a rotation radius. The plasma jet is contacted with the surface of the article so as to have a plasma jet footprint of predetermined dimension. The plasma jet is moved along the rotation radius of the article according to a velocity profile so that the surface of the article is heated to obtain a desired temperature distribution profile on the article surface as measured along the rotation radius.

It is one object of the present invention to provide a method which can achieve a relatively high process throughput without increasing potential article damager.

The foregoing and other objects, features, and advantages will become apparent from the detailed description of the preferred embodiments invention as illustrated in the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

The drawings, which are not drawn to scale, include:

FIG. 1, which is a schematic diagram of a plasma jet apparatus for carrying out the method of the present invention;

FIG. 2, which is a schematic diagram of an alternative plasma jet apparatus embodiment for carrying out the method of the present invention;

FIG. 3, which is a plan view of a circular wafer-like article, illustrating the footprint of a plasma jet applied thereto; and

FIG. 4, which is a graph showing the relationship of removal thickness of a polymer by ablation for a given velocity.

DETAILED DESCRIPTION OF THE INVENTION

Referring to FIGS. 1 and 2, a plasma jet **10** is produced by plasma jet generator **20** of any known type, which is located in a plasma jet process chamber (not shown). The ambient gas pressure of the plasma jet process chamber is maintained at about atmospheric pressure. In Figs. 1 and 2, the plasma jet generator **20** is preferably oriented so that the plasma jet **10** is directed upwards, relative to the force of gravity, towards a wafer-like article **30**, such as a silicon wafer, which is held in position on holder **40**. The article **30** may be secured to the holder **40** by a vacuum chuck or any other known article holding means. Article **30** having a surface to be treated **32** is oriented on the holder **40** such that the surface **32** faces the plasma jet **10**, which as illustrated in Figs. 1 and 2, is a generally downward orientation. Generally, during processing with the plasma jet, the holder **40** is rotated by motor **50** with revolution frequency **f**. Also, the article **30** is positioned on the holder **40** so that the rotation axis **Ha** of the holder **40** is coincident with the articles's inertial center or rotational axis **Wa**.

As will be explained in more detail below, the revolution frequency **f** of the article **30** about axis Wa, and corresponding duration, is chosen to be less than the time it takes for the temperature of a point on the surface heated at the beginning of a revolution to cool to the temperature the surface point had just before the beginning of the revolution of the article. Under these processing conditions, only a gradual heating of every point on the surface 32 of the article 30 is caused by the crossing of the plasma jet over the surface 32 of the article 30 during rotation thereof. By simultaneously moving the plasma jet along the articles' rotation radius and changing the rotation frequency of the wafer, high temperature gradients and thermal stress damage can be avoided.

The duration of the cooling of a point on the surface 32 of an article **30**, such as a silicon wafer, may be estimated by using well-known theory of non-stationary heat conductivity. For example, assuming that article **30** is a silicon wafer with thickness less than about 1 mm, has uniform temperature distribution in volume due to high heat conductivity and that it is cooled mainly by convectional heat transfer to ambient gas with constant temperature T_0 from both sides, the wafer's cooling may be described by the equation

$$mCh\frac{\delta(T_s(t)-T_0)}{\delta t}=2\alpha(T_s(t)-T_0)$$

where: m = Si density;
C = Si heat capacitance;
h = wafer thickness;
Ts(t) = wafer surface temperature;
To = ambient gas temperature; and
α = heat transfer coefficient.

Assuming that just before beginning of revolution (i+1), the temperature of wafer surface was T_i and during the beginning of (i+1) revolution the wafer surface was heated up to temperature T_{i+1}, then from the equation (1) the wafer revolution duration for which wafer surface temperature decreases from T_{i+1} back to T_i may be estimated:

$$t_{max}=\frac{mCh}{2\alpha}\ln\left(\frac{T_s(t)-T_0}{T_{i+1}-T_0}\right)=\frac{mCh}{2\alpha}\ln\left(\frac{T_i-T_0}{T_{i+1}-T_0}\right)$$

According to the method of the present invention, the duration of every wafer revolution should be chosen so that the temperature of the wafer surface caused by heating from the plasma jet is less than t_{max} and frequency f of wafer rotation should be chosen $f > f_{min} = 1/ t_{max}$.

According to the method of the present invention, the plasma jet **10** may be directed at an angle to the article's surface **32**. The angle between plasma jet **10** and the surface **32** influences the conditions of plasma flowing along surface **32**. Referring to Fig. 3, when the angle of the plasma jet **10** directed at the surface **32** of the wafer **30** is 90°, in other words, when the angle of the plasma jet **10** is normal to the surface **32**, the plasma spot or plasma footprint **11** on the surface **32** tends to be symmetrical and the plasma properties within plasma footprint **11** on the surface **32** are more uniform than when the plasma jet is directed at the wafer surface at an angle which is less than 90°. Preferably, in the method of the present invention, the plasma jet **10** is directed at the surface **32** in a normal orientation so as to provide the uniform footprint **11**.

Referring to FIGS. 1 through 3, according to the present invention, the plasma jet **10** is moved relative to the surface **32** typically between a first surface point having maximum rotation radius R_{max} and a second wafer surface point having a smaller rotation radius R_{min}. Movement of the plasma jet **10** may be done with any trajectory along the surface **32** because only the velocity vector component directed along the wafer rotation radius **R** is important for realization of this method. The relative movement of the plasma jet may be done by supporting the plasma jet on a rail **70** and connecting the generator **20** to a worm gear or screw transmission **80** which is driven by motor 60. The rail **70** is placed parallel to surface **32** and along wafer rotation radius **R**.

Because the plasma jet footprint **11** has limited cross sectional dimension **d** in the plane of the surface **32**, it is convenient to determine the instantaneous position of the plasma jet **10** relative to the surface 32 by the measuring or noting the distance between the article rotation axis **Wa** and the plasma jet axis **Ja**. Referring to FIGS. 1 and 2, the plasma jet **10** starts interacting with the surface 32

at the point of maximum rotation radius R_{max} when it is located at position (R+d/2). Due to the rotation of the motor **60**, the plasma jet generator **20** is moved along surface **32** and the plasma jet spot or footprint **11** on the surface **32** is moved towards the article surface points that have a minimal rotation radius, R_{min}.

There are two possible variations of movement of the article **30** relative to the plasma jet **10** and the two variations depend on the article type and location of its rotation axis **Wa**. Referring to FIG. 1, the first variant occurs when the rotation axis **Wa** is located out of the article **30** and at a distance which is more than d/2 from the outer edge **33** of the article **30**, or when the article **30** has an opening **34** with a dimension which is more than plasma jet footprint **11** dimension **d** and the wafer's rotation axis is located within the opening **34** at a distance which is more than **d/2** from its inner edge **36**. In these cases, minimal rotation radius R_{min} is more than half the plasma jet's footprint's **11** dimension **(d/2)**. Complete treatment of surface **32** is achieved after reaching a distance which is less than $R_{min}+d/2$ between rotation axis **Wa** and plasma jet footprint axis **Ja**. When the plasma jet 10 reaches its limit, it may be either turned off or moved further and stopped in the range between 0 and R_{min}-**d/2** without incurring damage to the article **30**.

Referring to FIG. 2, in the second variant, the rotation axis **Wa** is located out of the article **30** and positioned less than **d/2** from the outer edge **33** of the article **30** or the article has an opening **34** having a cross sectional dimension which is larger than the plasma jet footprint **11** dimension **d** and the article rotation axis **Wa** is located within the opening **34** and distanced less then **d/2** from the inner edge **36** or the article has an opening **34** with a dimension which is less than plasma jet footprint **11** dimension **d** or no opening at all ($R_{min} = 0$). In these cases minimal rotation radius R_{min} is less than half the plasma jet footprint's dimension **(d/2)**. Complete treatment of article surface **32** is achieved after reaching a location which is less than ($R_{min}+d/2$) between article rotation axis Wa and plasma jet footprint axis **Ja**. Then the plasma jet has to be either turned off

or moved back toward wafer points with R_{max} and stopped at the distance which is greater than (R_{max}+d/2) between the article rotation axis Wa and plasma jet axis Ja. In the later case wherein the plasma jet is not turned off, the article surface 32 is actually treated twice.

Relative movement velocity v(R) is changed by controlling the frequency of motor 50 having a shaft 55 which is connected to holder 40 to cause holder 40 to rotate. The velocity of the plasma jet 10 relative to the article 30 around any rotation radius R is given by $2\pi fR$, and is chosen to be greater than the velocity providing the plasma jet shift in the radial direction of the article, v(R). For one revolution of the article, the heat input from the plasma jet around the rotation radius spreads in the article material due to heat conductivity for a duration time equal to a revolution, t_{rev}. From the theory of non-stationary heat conductivity the heat spreading length l_{heat} for duration t_{rev} of wafer revolution may be estimated as:

$$l_{heat}=3\sqrt{at_{rev}}$$

$$a=\frac{\lambda}{mc}$$

where:

λ is the heat conductivity of wafer material.

The requirement for not developing a radial thermal gradient gives the condition:

$$v(R)t_{rev}>l_{heat}$$

or

$$v(R)>3\sqrt{\frac{a}{t_{rev}}}$$

For R < d/2, the maximum velocity in the radial direction $v_{max}(R)$ is given by the requirement for uniform treatment, that the plasma jet shift in the radial direction be less than the plasma jet dimension D over the duration of one revolution, t_{rev}.

The plasma jet foot print 11 on the wafer surface has dimension d, which is about several centimeters and non-uniform distribution of heat flux. That distribution may be measured by calorimeter or any other known means.

Referring to Fig. 3, from the theory of non-stationary heat conductivity, the temperature of an article wafer at a point with coordinate (R, W_O) may be described by differential equation:

$$mCh\frac{\delta(\Delta T(t))}{\delta t}=q_{pl}(\rho(t),\varphi(t))-q_{cool}(R,W_0\Delta T(t)) \qquad (*)$$

where:

$\Delta T(t)=T_s(t)-T_o$;

$T_s(t)$ is article surface temperature at the point (R,W_o) and is less than temperature of article surface material damage;

T_o is the ambient gas temperature;

$q_{pl}(\rho(t),\varphi(t))$ is the heat flux distribution from the plasma jet in polar coordinates with instantaneous center at point = 0; and

q_{cool} (R, Wo, $\Delta T(t)$) is the cooling heat flux at wafer surface point with coordinates (R, W_o).

The article is rotated around the axis through the point R=0 and at the same time the distance r(t) between wafer rotation axis and plasma jet center is changed due to relative plasma jet to article movement, v(R) and consequently so:

$$\rho(t)=R^2-r^2(t)-2Rr(t)\cos(W(t)+W_o) \qquad (**)$$

$$\varphi(t)=\arctan(R\sin(W(t)+W_0)/(r(t)-R\cos(W(t)+W_o)))$$

Solution of the equations (*) and (**) by routine numeric integration allows the determination of function r(t) and W(t) which provides a method for achieving required article surface temperature at every article surface point for concrete given conditions. Relative movement velocity function is determined by differentiation of r(t).

For practical use the relative movement velocity function may be found by routine experimental procedure. For simplicity the rotation frequency f is fixed and the article 30 is to be heated from initial temperature To the temperature $T_w(R)$. In step 1, the velocity $v(R)$ is chosen arbitrarily from the range limited by the above mentioned conditions and may be taken as constant. In step 2, one plasma jet pass along the article surface 32 is made. In step 3, the temperature distribution $T_{heat}(R)$ along article's radius R is measured. In step 4, the real temperature distribution $T_{heat}(R)$ is compared with desirable $T_w(R)$ and if difference between $T_{heat}(R)$ and $T_w(R)$ is unacceptable then the velocity function is changed according to the relation $v(R) = ((T_{heat}(R)-T_o)/(T_w(R)-T_o))v(R)$ and the procedure is repeated from Step 2. If the difference between $T_{heat}(R)$ and $T_w(R)$ is acceptable then the procedure is stopped and found optimal velocity function $v_{opt}(R)$ may be used for article treatment.

This procedure may be extended to a general iterative procedure to obtain an optimal velocity function, $v_{opt}(R)$. For each iteration, a new velocity function, $v_{i+1}(R)$ can be obtained from the previous velocity function $v_i(R)$; the measured temperature profile across the wafer, $T_{heat,i}(R)$, obtained when executing the velocity function $V_i(R)$; and the previously measured temperature profile, $T_{heat,\ i-1}(R)$, obtained when executing the velocity function $v_{i-1}(R)$:

$$v_{i+1}(R) = (T_{heat,\ i}(R) - T_{heat,\ i-1}(R))/T_w(R)-T_{heat,\ i-1}(R))V_i(R) \qquad \text{(iii)}$$

These iterations can be repeated until the measured temperature at all points, $T_{heat,\ i}(R)$ is acceptably close to the desired temperature $T_w(R)$. The velocity function for this iteration can then be used for the temperature treatment process and is an optimum velocity function, $v_{opt}(R)$.

In practice, to prevent damage to the article surface 30 due to thermal stress, the temperature distribution after every pass will be constant to within some acceptable temperature difference, T_d. The temperature of all points on surface 32, at all radii, should be within an acceptable temperature difference of the surface point with minimum rotation radius or $T_w(R) = T(R_{min}) \pm T_d$.

Having determined $v_{opt}(R)$, the velocity function, $v^*_{opt}(R)$, to change the article temperature from $T_w(R)$ to another desired temperature $T^*_w(R)$ may be obtained by:

$$v^*_{opt}(R) = ((T^*_w(R) - T_0)/ T_w(R) - T_0)v_{opt}(R) \qquad \text{(iv)}$$

The temperature to which the article should be heated depends on application requirements, for example:

- 1000 - 1100°C for poly-Si layer recrystallization;
- 900 - 1000°C for activation of ion implanted dopants;
- 500 - 600°C for reflowing BPSG; and so on.

Plasma jet treatment may be used for thin polymer film removal or polymer photo resist stripping from the article surface. For these applications, the relative movement velocity along article rotation radius is chosen less then velocity providing heating polymer film surface on article surface up to polymer ablation temperature. Specific polymer ablation temperature is usually very close to polymer melting temperature and may be obtained from handbooks on polymer properties. The value $v_{abl}(R)$ which provides that article temperature T_{abl} is determined from equation (*) or from experimental data and relation that follows from equation (iv):

$v_{abl}(R)=((T_{abl}-T_o)/(T_w-T_o))*v_{opt}(R)$,

where: $v_{opt}(R)$ is the relative movement velocity known from the experiments providing wafer heating to the temperature T_w.

If the polymer ablation temperature is unknown then the $v_{abl}(R)$ may be found experimentally by the following procedure. For given inert gas plasma jet parameters, the polymer removal thickness Δh is measured for different values

$v(R)$. A typical plot Δh versus $v(R)$ is shown at FIG. 4. The $v_{abl}(R)$ is the value where the curve has sharp slope change.

The velocity $v_{abl}(R)$ is threshold for starting of polymer ablation. All velocity values $v(R) < v_{abl}(R)$ provide polymer ablation and removal without dependence on whether the plasma jet consists of chemical reactants or not. The smaller $v(R)$, the greater removal thickness during each pass.

To provide uniform ablation removal of the polymer within the article, the relative movement velocity $v(R)$ $(v(R) < V_{abl}(R))$ along article rotation radius **Wa** is changed depending on the distance between plasma jet footprint **11** at the article surface **32** and article rotation axis **Wa** so that the removal thickness of the polymer at article surface points at all rotation radii be equal to removal thickness at article surface points at the minimum rotation radius.

For practical use, the velocity function for the relative movement of the plasma jet relative to the axis of rotation of the article **30** may be determined directly from measured polymer ablation removal by the following steps. First, the velocity $v(R)$ is chosen from the range $v(R) < v_{abl}(R)$; it may be taken as the velocity function that provides uniform heating of the article. Second, one plasm jet pass over the article is made. Third, the polymer thickness removal $\Delta h(R)$ is measured along the article radius in steps Δr. An average polymer thickness removal Δh_{av} can then be calculated:

$$\Delta h_{av} = (\Delta r / R_{max}) \Sigma \Delta h(R_i)$$

Fourth, the measured polymer removal $\Delta(R)$ is compared to the average removal $\Delta h(R)$; if the difference between Δh_{av} and $\Delta h(R)$ is unacceptable, a new velocity function $v^*(R)$ is recalculated according to the function $v^*(R) = (\Delta h(R)/\Delta h_{av})v(R)$. If the difference between Δh_{av} and $\Delta h(R)$ is acceptable, then the procedure is stopped and then an optimum velocity function $v_{opt}(R) = v(R)$ may be used for polymer removal. In general, an iterative procedure similar to that described for determining an optimum velocity profile for temperature treatment, equation (iii), could be used for repeated iterations with measured polymer removal.

To obtain the desired polymer removal thickness Δh_{des} the velocity $v_{des}(R)$ may be obtained as:

$v_{des}(R)=(\Delta h_{des}/\Delta h_{av})*v_{opt}(R)$.

If the polymer layer thickness H to be removed is more than the removal thickness Δh for one pass, the treatment is repeated until complete polymer removal is achieved. The minimal necessary quantity N of required passes may be estimated as: $N=H/\Delta h$.

Referring to FIG. 4, note that for velocity values $v(R) > v_{abl}(R)$, removal by ablation with an inert gas plasma jet is insignificant. In the case that the plasma jet contains chemically active reactants, such as oxygen or hydrogen, then the polymer is removed by the plasma jet by chemical reactions, commonly referred to as ashing, but with a much lower rate than is possible by ablation removal.

For providing plasma etching of article material or other materials on the article's surface **32**, a reactant which is able to produce volatile chemical substance with the material components is added to plasma jet. The greater the reactant concentration in the plasma jet **10**, the greater the etching rate. The reactant may be fluorine containing gas (freon, SF_6, NF_3, etc.) for etching Si, poly-Si, SiO_2, Si_3N_4, other Si-based materials, M_o, Ti, W, Cr. It may be chlorine containing gas ($CC1_4$) for etching Aluminum. It may be oxygen or hydrogen for etching polymers such as photo resists, or polyimide.

To provide uniform etch removal of the material within the article **30**, the relative movement velocity of the plasma jet **10** along the article's rotation radius R is changed depending on the distance between the plasma jet footprint **11** at the article surface **32** and the article rotation axis **Wa** to provide a removal thickness of wafer surface material at wafer surface points at all rotation radii be equal to removal thickness at the wafer surface point with minimal rotation radius. During one plasma jet pass along the wafer, the etch removal rate and etch uniformity are determined by the relative movement velocity function $v_{etch}(R)$ for given plasma jet parameters and reactant concentration. For practical use the velocity of function

$v_{etch}(R)$ may be found by an experimental procedure provided by the following steps. In the first step, the velocity $v_{etch}(R)$ may be taken as the velocity function providing uniform heating of the article. In the second step, one plasma jet pass along through the wafer is made. In the third step, etch removal thickness $\Delta h(R)$ along article radius is measured in steps Δr. Average material removal thickness Δh_{av} is calculated as

$$\Delta h_{av} = \frac{\Delta r}{R_{max}} \sum_{R_i=R_{min}}^{R_i=R_{max}} \Delta h(R_i)$$

In the fourth step, the real etch removal thickness $\Delta h(R)$ is compared with Δh_{av} and if the difference between $\Delta h(R)$ and Δh_{av} is unacceptable then a new velocity function $v^*_{etch}(R)$ is calculated according to the relation $v^*_{etch}(R) = (\Delta h(R)/\Delta h_{av}) v_{etch}(R)$ and the procedure is repeated from the second step. If the difference between $\Delta h(R)$ and Δh_{av} is acceptable then the procedure is stopped and the optimal velocity function $v_{opt}(R)$ may be used for uniform etching.

To obtain the etch removal thickness desired Δh_{des}, the velocity $v_{des}(R)$ may be obtained from the function $v_{des}(R) = (\Delta h_{des}/\Delta h_{av}) v_{etch}(R)$. Again, as described for determining the velocity function for heat treatment, a general iterative procedure similar to equation (iii) can be used to determine an optimum velocity profile for etching.

If the material layer thickness H_{etch} to be removed is more then removal thickness Δh for one pass, the treatment is repeated until necessary etch depth is reached. The minimal necessary quantity N of the passes may be estimated as: $N = H_{etch}/\Delta h$.

If the etching is conducted through a polymer photo resist mask, the velocity function for relative movement of the plasma jet should be chosen to be more than the ablation threshold velocity for the polymer material to avoid ablation removal of the polymer mask.

To conduct plasma enhanced chemical deposition of a thin layer on a wafer surface at least one reactant gas which is able to produce a nonvolatile chemical substance on the wafer surface is added to the plasma jet **10**. As an example, adding SiH_4 to the plasma jet **10** allows deposition of amorphous or poly Si if the plasma jet and process chamber ambient gases are inert. If a mixture of SiH_4 or silica organic substance vapor and oxygen is added to the plasma jet, silicon oxide film is deposited onto wafer surface.

For uniform material deposition the relative movement velocity $v_{dep}(R)$ along wafer rotation radius is changed depending on distance between plasma jet at the wafer surface and wafer rotation axis to provide a deposited layer thickness at wafer surface points at all rotation radii that is equal to the deposited layer thickness at wafer surface point with minimal rotation radius.

In practice, the velocity function $v_{dep}(R)$ may be found by routine experimental procedure by the following steps. In the first step, the velocity $v_{dep}(R)$ may be taken as velocity providing uniform heating of the wafer. In the second step, one plasma jet pass along through the wafer is made. In the third step, material deposition thickness $\Delta h(R)$ along wafer radius is measured in increments Δr. The average deposition thickness Δh_{av} is calculated as

$$\Delta h_{av} = \frac{\Delta r}{R_{max}} \sum_{R_i=R_{min}}^{R_i=R_{max}} \Delta h(R_i)$$

In the fourth step, the real deposition thickness $\Delta h(R)$ is compared with Δh_{av} and if the difference between $\Delta h(R)$ and Δh_{av} is unacceptable then a new velocity function **V.dep** is calculated according to the relation $v^*_{dep}(R) = (\Delta h(R)/\Delta h_{av}) v_{dep}(R)$ and the procedure is repeated from the second step. If the difference between $\Delta h(R)$ and Δh_{av} is acceptable then the procedure is stopped and found optimal velocity function $v_{opt}(R)$ may be used further for uniform deposition.

To achieve desirable deposition thickness Δh_{des} the velocity $v_{des}(R)$ may be obtained from the function: $v_{des}(R)=(\Delta h_{des}/\Delta h_{av})*v_{dep}(R)$. Again, as described for determining the velocity function for heat treatment, a general iterative procedure similar to equation (iii) can be used to determine an optimum velocity profile for deposition.

If the material layer thickness H_{dep} to be deposited is more than the deposition thickness Δh for one pass, the treatment steps are repeated until necessary layer thickness is reached. The minimum necessary quantity N of passes may be estimated as :

$N=H_{dep}/\Delta h$.

The methods described for article processing by heating, polymer ablation, etching and deposition may be combined to give multiple processes in a single run. The key factor is control of and capability to change the article temperature described in the above sections. Such an application is to pattern a polysilicon film through a photo resist mask, and then strip the mask in a single process: (1) pattern a polysilicon film by etching the film through a pattern photoresist mask at a low temperature, high average velocity, $v(R) > V_{abl}(R)$, and (2) follow by stripping the photoresist mask by an ablative process using inert gas, no chemically reactive gasses, at a higher temperature, lower average velocity, $V(R) < V_{abl}$.

As will be understood from the foregoing description, according to the present invention, the method may be employed for several plasma jet operations. It is to be understood that the embodiments described herein are merely illustrative of the principles of the invention. Various modifications may be made thereto by persons skilled in the art which will embody the principles of the invention and fall within the spirit and scope thereof. Hence, the present invention is deemed limited only by the appended claims and the reasonable interpretation thereof.

WHAT IS CLAIMED IS:

1. A method for treating the surface of an article with a plasma jet, the method comprising the steps of:

(a) providing an article with a surface to be treated;

(b) providing a plasma jet;

(c) rotating the article about an axis, wherein the rotation defines a rotation radius extending from the axis;

(d) contacting the article surface with the plasma jet to form a plasma jet footprint having a predetermined dimension on the article surface; and

(e) moving the plasma jet footprint along the rotation radius in the radial direction according to a velocity profile along the rotation radius so as to apply heat to the article surface to obtain a desired temperature distribution profile on the article surface along the rotation radius.

2. A method for treating the surface of an article with a plasma jet, the method comprising the steps of:

(a) providing an article with a surface to be treated;

(b) providing a plasma jet;

(c) rotating the article about an axis, wherein the rotation defines a rotation radius extending from the axis;

(d) contacting the article surface with the plasma jet to form a plasma jet footprint having a predetermined dimension on the article surface;

(e) moving the plasma jet footprint relative to the article surface along the rotation radius according to a first velocity profile so as to heat the article surface;

(f) measuring the temperature of the article surface along the rotation radius to obtain a measured temperature distribution for the article surface along the rotation radius;

(g) comparing the measured temperature distribution for the article surface with a desirable temperature distribution profile for the article surface along the rotation radius;

(h) determining a second velocity profile for moving the plasma jet footprint relative to the article surface along the rotation radius that will obtain the desirable temperature distribution profile for the article surface along the rotation radius; and

(i) moving the plasma jet footprint relative to the article surface along the rotation radius according to the second velocity profile so as to heat the article surface to obtain the desirable temperature distribution profile.

3. The method according to claim 2, wherein the second velocity profile of the plasma jet footprint relative to the article surface along the rotation radius is determined according to the function $vdes(R) = ((T_{heat}(R)-T_o)/(T_w(R)-T_o))*v(R)$, wherein vdes(R) is the velocity of the plasma jet footprint relative to the article surface at a point on the radius necessary to heat the article surface to a desired temperature, $T_{heat}(R)$ is the measured temperature of the article surface at the point on the radius, T_o is the initial temperature of the article surface, $T_w(R)$ is a desired temperature for the article surface at the point on the radius, and v(R) is the initial velocity of the plasma jet footprint relative to the article surface at a point on the radius.

4. The method according to claim 3, wherein the temperature of the article can be controlled to a uniform temperature in the range of about 30° C to 1200°C.

5. A method for treating the surface of an article with a plasma jet, the method comprising the steps of:

(a) providing an article with a surface to be treated;

(b) providing a plasma jet for etching material from the article surface;

(c) rotating the article about an axis, wherein the rotation defines a rotation radius extending from the axis;

(d) contacting the article surface with the plasma jet to form a plasma jet footprint having a predetermined dimension on the article surface;

(e) moving the plasma jet footprint relative to the article surface along the rotation radius according to a first velocity profile so as to remove material from the article surface;

(f) measuring the thickness of the article surface along the rotation radius to obtain a measured thickness distribution for the article surface along the rotation radius;

(g) comparing the measured thickness distribution for the article surface with a desirable thickness distribution profile for the article surface along the rotation radius;

(h) determining a second velocity profile for moving the plasma jet footprint relative to the article surface along the rotation radius that will obtain the desirable thickness distribution profile for the article along the rotation radius; and

(i) moving the plasma jet footprint relative to the article surface along the rotation radius according to the second velocity profile so as to heat the article surface to obtain the desirable thickness distribution profile.

6. The method according to claim 4, wherein the second velocity profile of the plasma jet footprint relative to the article surface along the rotation radius is determined according to the function $v_{des}(R)=(\Delta h_{des}/\Delta h_{av})*v_{etch}(R)$, wherein $v_{des}(R)$ is the desired velocity of the plasma jet footprint relative to the article surface at a point on the radius necessary to remove material from the article surface to obtain a desired thickness, Δh_{des} is the desired thickness at the point on the radius, Δh_{av} is the measured average thickness and $v_{etch}(R)$ is the initial velocity of the plasma jet footprint relative to the article surface at the point on the radius.

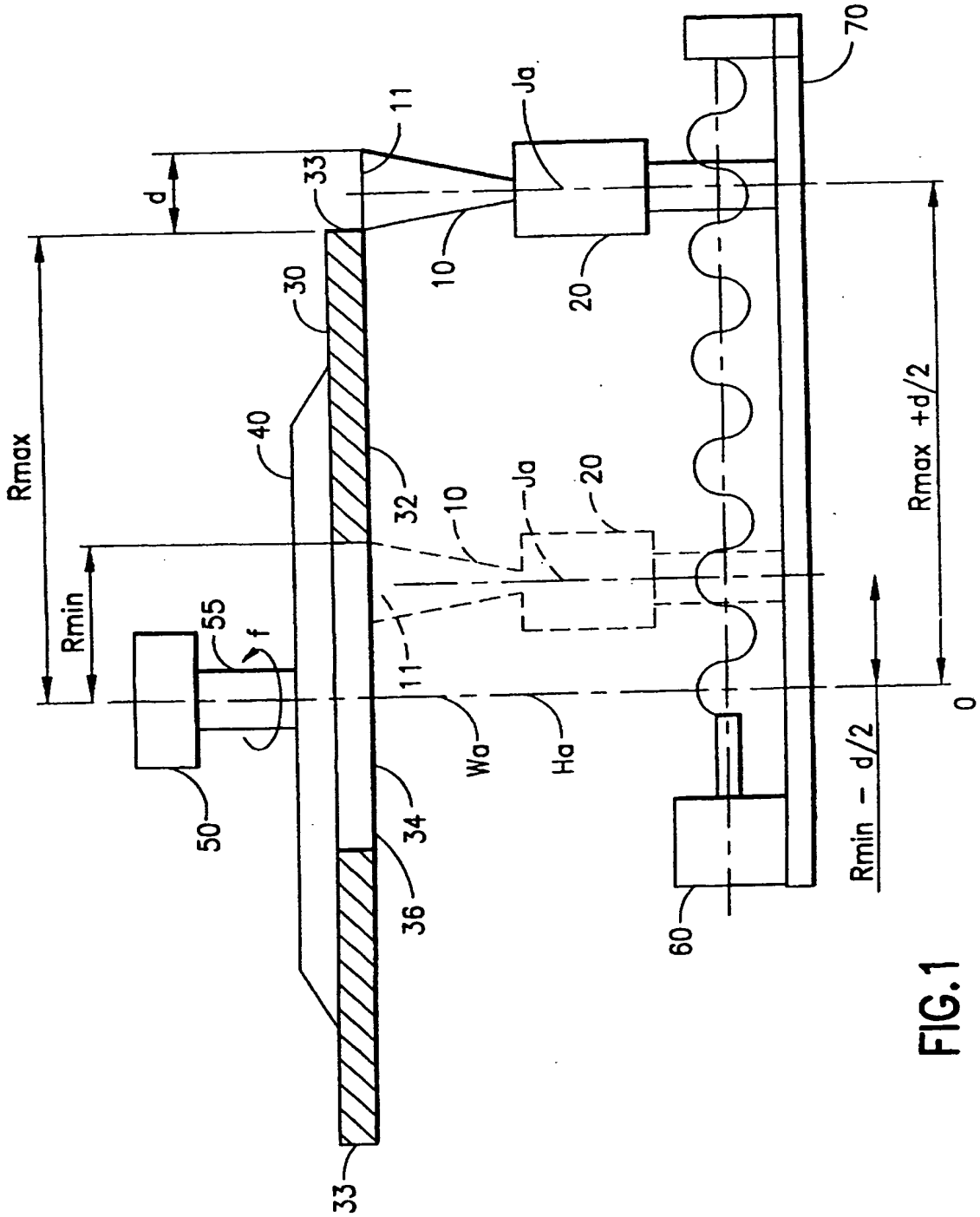
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FIG.1

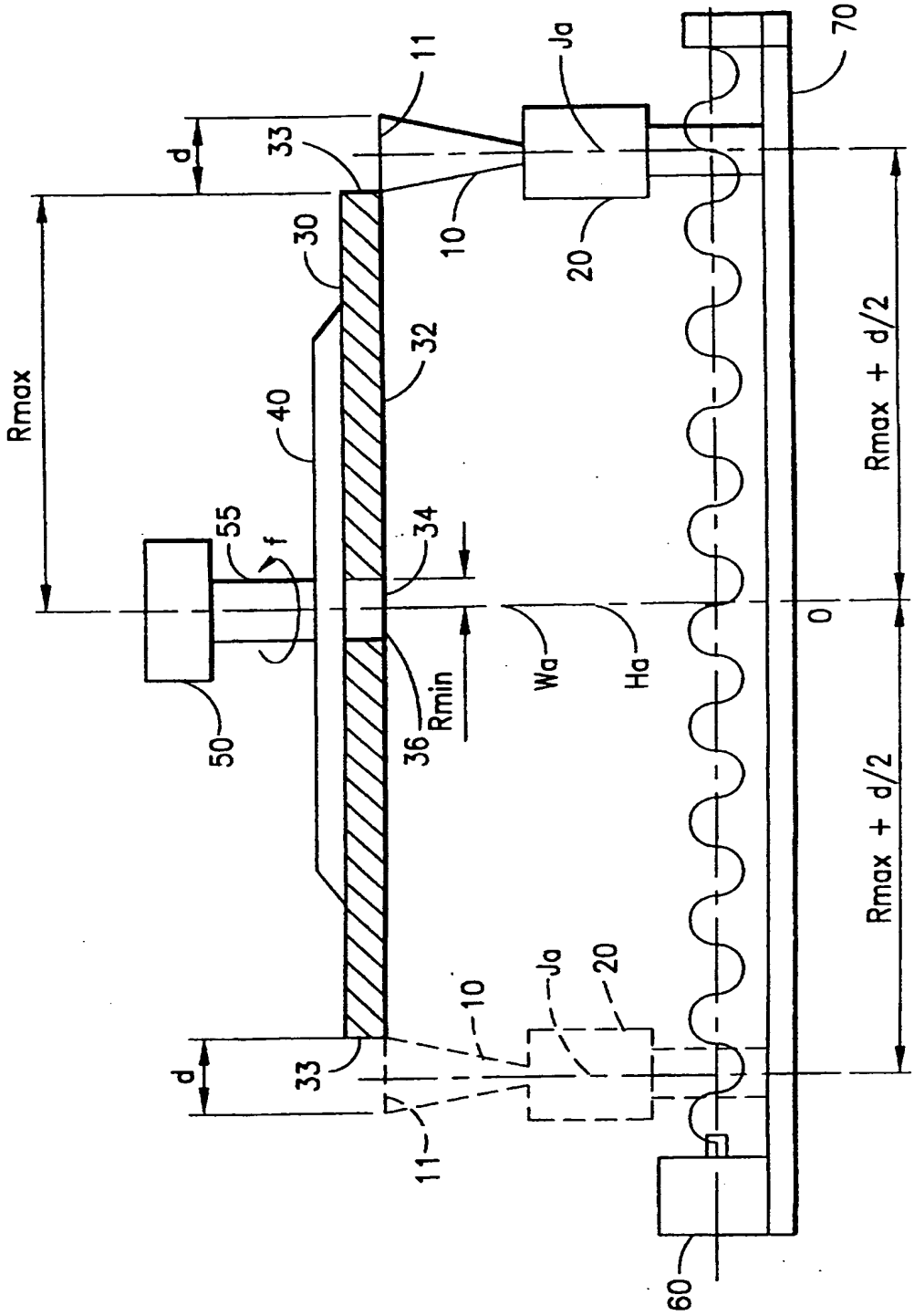
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FIG.2

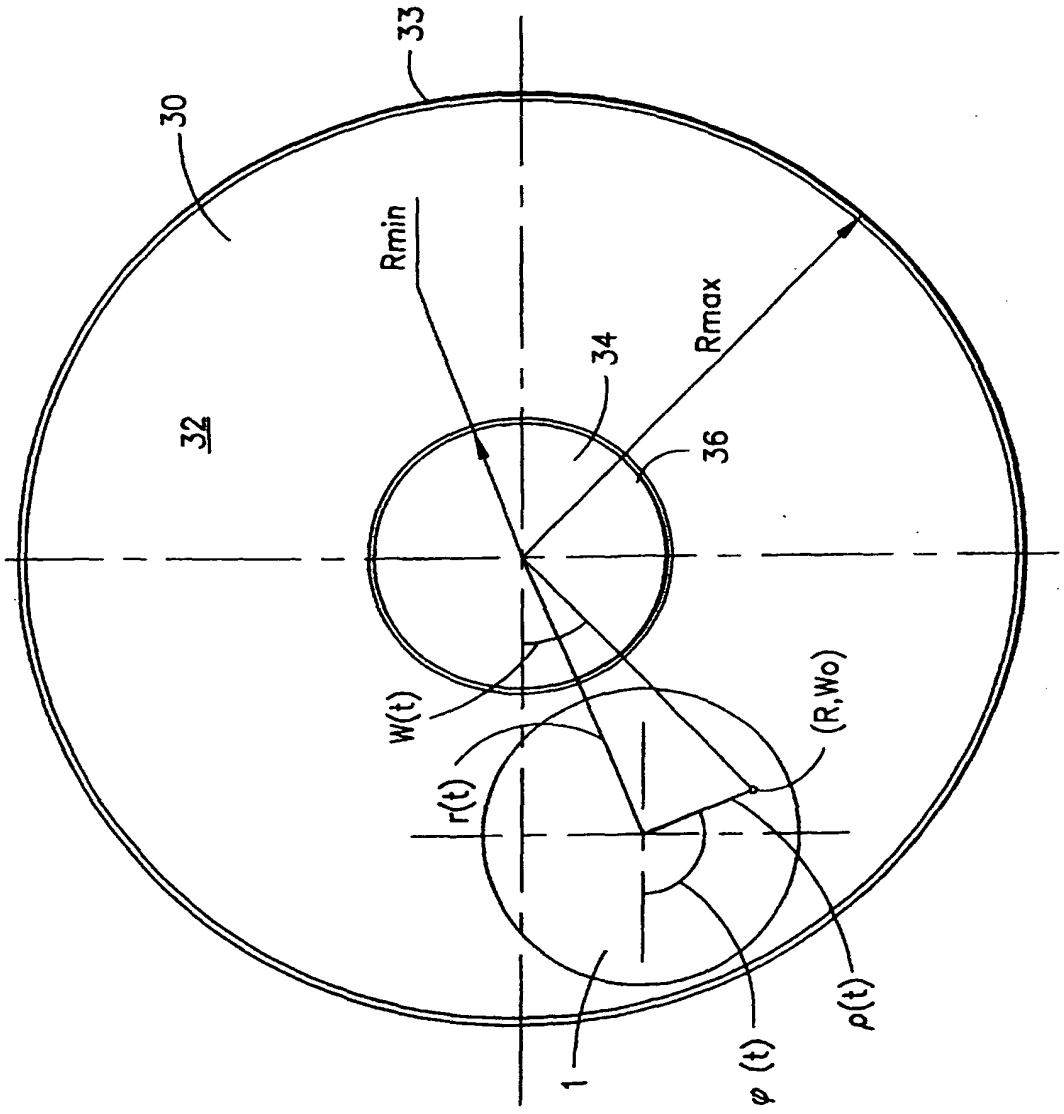

FIG.3

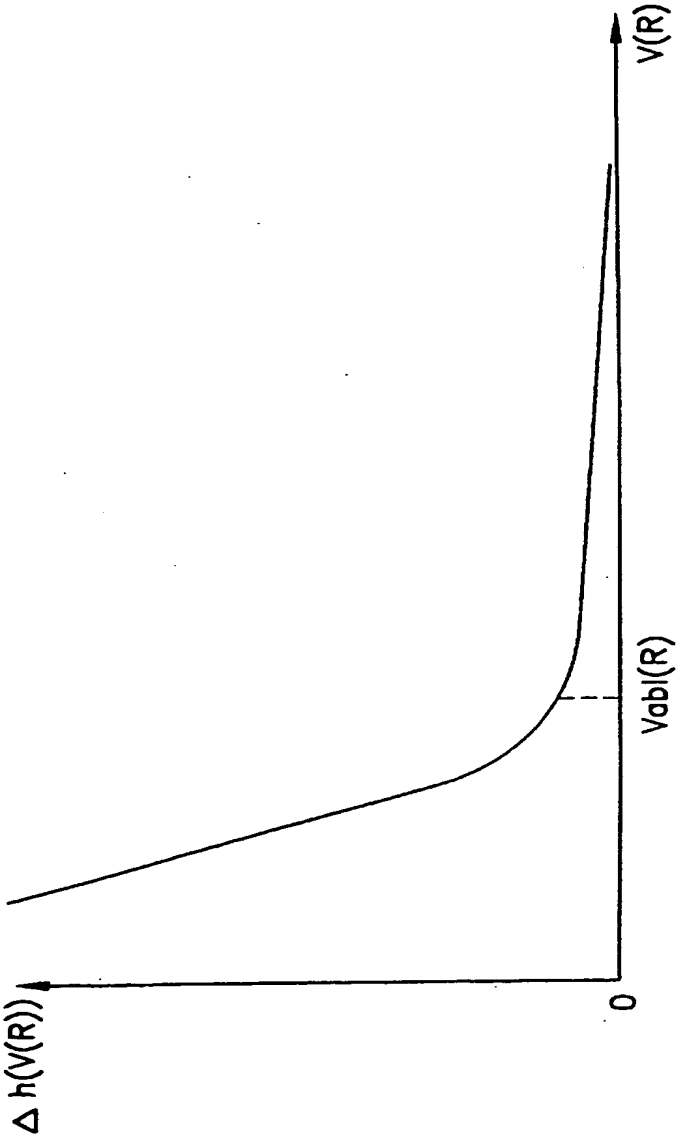

FIG.4

INTERNATIONAL SEARCH REPORT

Interna J Application No
PCT/US 97/09069

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H01J37/32 H01L21/00 C23C16/50 C23C16/46

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 C23C H01J

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	PATENT ABSTRACTS OF JAPAN vol. 095, no. 010, 30 November 1995 & JP 07 172986 A (NIPPONDENSO CO LTD), 11 July 1995, see abstract ---	1-6
A	PATENT ABSTRACTS OF JAPAN vol. 017, no. 391 (C-1087), 22 July 1993 & JP 05 070290 A (HITACHI CHEM CO LTD), 23 March 1993, see abstract ---	1-6
A	WO 91 17285 A (SCHMITT TECHNOLOGY ASSOCIATES) 14 November 1991 see page 14, paragraph 2; figure 4 --- -/--	1-6

[X] Further documents are listed in the continuation of box C. [X] Patent family members are listed in annex.

* Special categories of cited documents :

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier document but published on or after the international filing date

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"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art.

"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
23 September 1997	08. 10. 97

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+ 31-70) 340-2040, Tx. 31 651 epo nl, Fax (+ 31-70) 340-3016	Patterson, A

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INTERNATIONAL SEARCH REPORT

Interna l Application No
PCT/US 97/09069

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	EP 0 545 460 A (PHILIPS PATENTVERWALTUNG ;PHILIPS NV (NL)) 9 June 1993 see claims 1,5; figures 1,2 -----	1-6

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INTERNATIONAL SEARCH REPORT

Interna J Application No
PCT/US 97/09069

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WO 9117285 A	14-11-91	US 5356672 A	18-10-94
		CA 2082432 A	10-11-91
		US 5256205 A	26-10-93
EP 0545460 A	09-06-93	DE 4138541 A	27-05-93
		DE 59208175 D	17-04-97

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